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MECHANICAL ENGINEERING

Name of Project

STUDY THE PLACEMENT OF WIND TURBINES ON FLOATING PLATFORMS

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INDEX

Chapter 1: ABSTRACT……………………………………………………………1

Chapter 2: ADVANTAGES………………………………………………………2

- **2.1 Introduction………………………………………………………………2**
- **2.2 Benefits and potential of offshore wind against the continental…………………………………………………………………3**

Chapter 3: OFFSHORE STRUCTURES………………………………………..6

- **3.1 Introduction………………………………………………………………..6**
- **3.2 Historical review…………………………………………………………..7**
- **3.3 Types of structures: Foundations…………………………………………9**
  - **3.3.1 Supported on the seafloor……………………………………….10**
  - **3.3.2 Floating…………………………………………………………….17**

Chapter 4: POWER SYSTEM…………………………………………………..24

- **4.1 Undersea cable…………………………………………………………..24**

Chapter 5: LOAD STUDY……………………………………………………….27

- **5.1 Introduction……………………………………………………………….27**
- **5.2 Structural design…………………………………………………………..28**
- **5.3 Characterization of stresses on the offshore platform…….31**
- **5.4 Actions due waves………………………………………………………32**
  - **5.4.1 Time control. Classical hydrodynamics……………………32**
  - **5.4.2 Morison theory……………………………………………………..38**
- **5.5 Action due wind…………………………………………………………..40**
- **5.6 Other actions………………………………………………………………41**

Chapter 6: COSTS………………………………………………………………42

Chapter 7: FUTURE IN EUROPE……………………………………………..44

Chapter 8: BIBLIOGRAPHY…………………………………………………..47

CHAPTER 1: ABSTRACT

The need to generate electricity seeking an alternative to nuclear energy is required to develop new energy systems.

For this, one of the most ambition plans to occupy the open ground that we have in the sea, to implement new technologies to generate energy.

An alternative is to construct and install offshore structures in these wind turbines to harness wind power.

Due to its location, and the need to build them in ever greater depths at lower cost, are in constant development.

CHAPTER 2: ADVANTAGES

2.1 INTRODUCTION

The advantages of offshore wind energy is due to the characteristic of wind at sea, which is much more constant than on land, since there are no hills or buildings which hinder its way and often the wind being more intense than in allowing land produce more energy in less time.

Another of the advantages of offshore wind energy is to avoid noise problems that wind turbines produce that prevent the building field in their home environment. No limitations on land use, taking more space than on land and may place more easily than on land in areas other than for migrating birds.

It is a source of energy that does not pollute and inexhaustible, slows the depletion of fossil fuel helping to prevent climate change.

Each kWh of electricity generated by wind power instead of coal, avoid:

0.6 Kg of CO_2 (Carbon dioxide).

1.33 g of SO_2 (Sulfur dioxide).

1.67 g of NO_x (Nitrogen oxide).

And that same generator produces the same amount of energy obtained by burning 100 kg of oil daily, achieving a similar effect to 200 trees.

But the main disadvantage is the high cost of building and connecting with the distribution of electrical energy.

2.2 BENEFITS AND POTENTIAL OF OFFSHORE WIND AGAINST THE CONTINENTAL

Taking advantage of offshore wind energy began in shallow waters of the North Sea, motivated by the search for sites with potential for more favorable winds than alternatives in the continental Europe.

But these new offshore locations in deep waters have additional benefits, so that the main advantages of offshore wind to include are:

- Best wind regimes.
- Low visual impact.
- Promotion of a new European power grid.
- Development of higher powered turbines.

Concerning the former, the following shows the maps of winds in Europe:

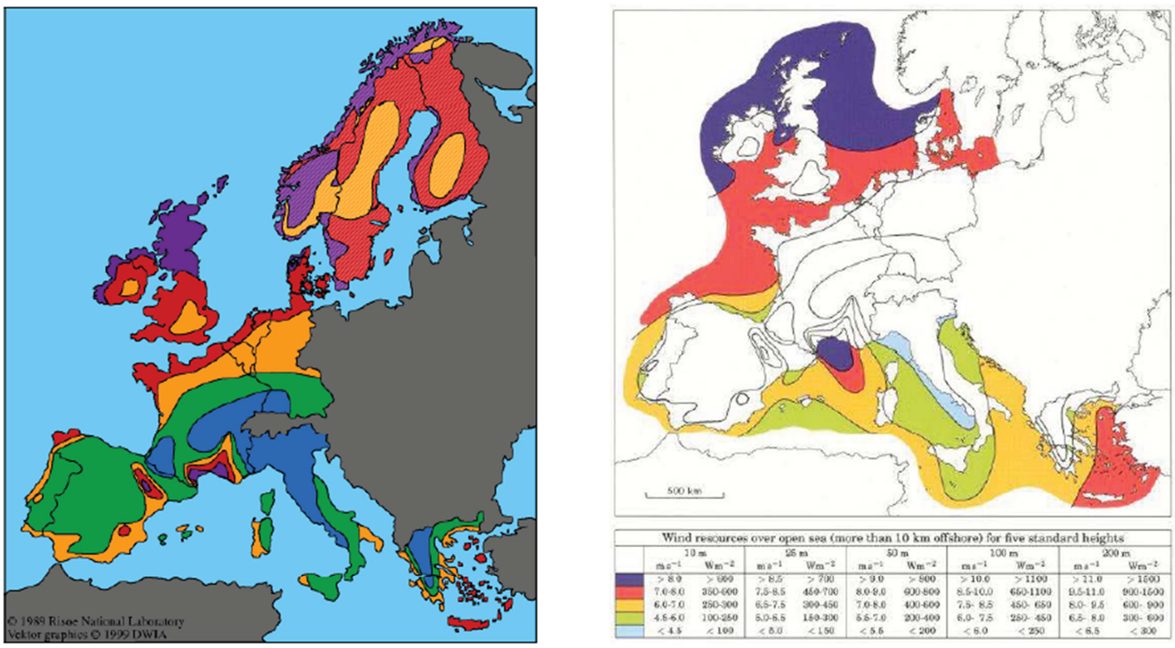

Figure 1: Wind map of Europe (Continental in left and marine at right)

The potential difference of continental and marine winds can be seen in the two previous images. In fact, the offshore wind resource is up to 50% on the continent due to less turbulent regimes and regular wind in those areas.

It is remarkable mainly the North Sea area where the winds actually produce more energy content. Furthermore, in the North Sea takes the characteristic that is on a shelf so that one can find depths of no more than 40m rather long distance on the coast. This is very important to the subject of foundations, as the cost thereof increases exponentially with the depth of placement.

The lower visual impact has an advantage because of the distance from its the mainland, but as long as is sufficiently close to large population-based seats concentrated on the coasts, because the fact of having a power source close to the consumer end clearly decreases transmission losses.

On the other hand, with the creation of offshore wind farms will promote the emergence of a European electricity network can connect to the mainland UK and can also join Denmark, Germany, Norway and Sweden across the North Sea.

The whole development of offshore wind energy has been made possible by its previous on land.

Continental Wind power has experienced a high technological development, which has placed it in the kWh cost levels similar to plants of fossil fuel.

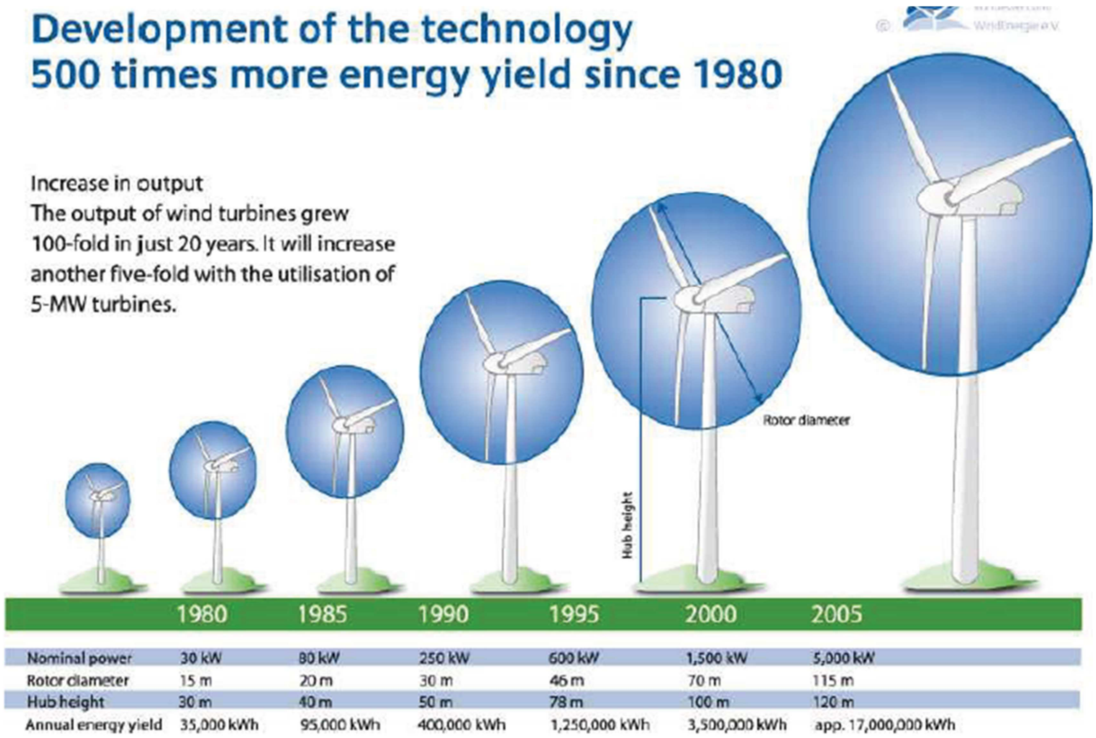

Figure 2: Development of the wind turbines

The picture shows the development of size and power of the turbines in the last 30 years. The development of this technology allows the installation of more power in a single platform, thereby reducing the costs associated with the substructure, foundation and grid connection is a very high percentage of spending on shore turbines.

To counter the large investments needed for the installation of these parks have developed multiple research possible synergies. The structures that serve the function of turbine foundations could be used as fish farms, desalination plants or systems available use of tidal power.

CHAPTER 3: OFFSHORE STRUCTURES

3.1 INTRODUCTION

An offshore structure is a structure located at the sea, therefore is subjected to the wave action and, in addition, weather conditions. These phenomena are important to keep in mind in the design and calculation of these structures, because the weather is one of the main causes of failure in offshore structures.

Offshore structure can be fixed to the seafloor or floating and their primary function for which they were designed for is the exploration and production oil and gas. Nowadays other functions have emerged as use of energy from the sea, airports, support for wind turbines and base building.

But, for all these functions can be apply the same principles of design and construction.

3.2 HISTORICAL REVIEW

The birth of the offshore industry emerged in 1947 with Kerr-McGree in the Gulf of Mexico reaching a depth of 4.6 meters to exploit an oil well. The structure consisted of a wooden roof of 11.6 x 21.6 m supported on piles reaching a depth of 31.7 m.

From this time, innovations were introduced in various types of offshore structures, both fixed and floating, located in deeper places and more hostile environmental conditions.

A major breakthrough came with the Cognac platform, fixed structure which consisted of three separate structures arranged one over another, with which reached 312 m depth. The greatest depth reached with a fixed structure of this type is achieved in 1991 with 412 m. From here, the search of greater depth with fixed structures results highly expensive and difficult to install.

Figure 3: Cognac Platform

Faced with this situation, and innovative and cheaper alternative arose, the tower called Compliant, which allows the deformation of its elements to support the loads and was supported by a set of braces to resist hurricanes.

Figure 4: Compliant Tower

All these mentioned structures have been built in steel; however in the eighties some were built with concrete in hostile waters in the North Sea.

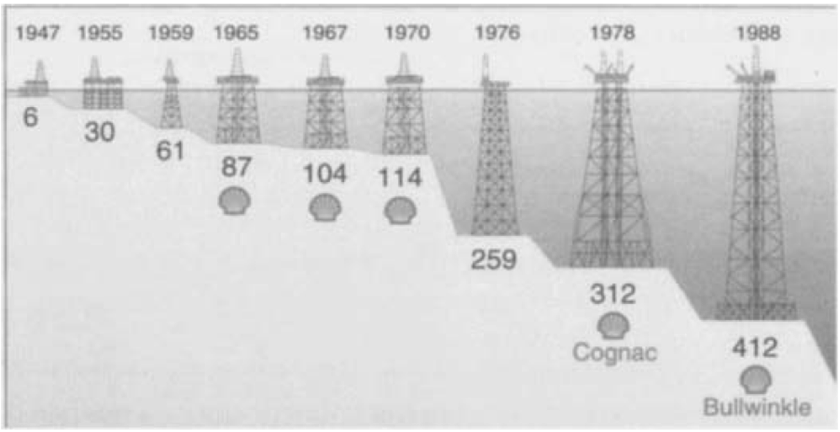

Figure 5: Evolution of offshore platforms in meters

Finally in 1975 was settled in the UK North Sea's first floating system, which was a converted semi-submersible. With the development of these floating platforms the field of deep water offshore structures was redefined reaching depths of 3000 meters.

3.3 TYPES OF STRUCTURES: FOUNDATIONS

For being the sea the base of this work, in this section we refer to the foundation of marine elements installed, such as wind turbines, substations and meteorological towers.

Although the function of a foundation is the same at sea than on land, there are marked differences between them, by the aggressive marine environment. This aggressive affects both the design phase, since the actions to which the structure faces are of greater magnitude and importance than on land, as in the construction phase and maintenance at sea because the weather conditions determine everything.

The market of the offshore wind engineering is a modern and immature market, which means that the experience related to wind turbine foundations, substations and meteorological towers in the sea is low. We must therefore base on the offshore oil market with many years of research.

Offshore structures can be classified into two groups: those supported in the seafloor and floating.

3.3.1 SUPPORTED ON THE SEAFLOOR

Supported structures on the seafloor, except for those built in concrete, are weld with hollow profile in steel who act as a framework that supports the weight of the total structure and the forces due to waves, sea current and wind.

There are two types:

- Fixed: They are considered fixed when the lowest natural frequency of the bending movement of the structure is above the highest frequency excitation of the significant wave. They behave as a rigid body and must resist every dynamic forces of the environment. They are surface foundations that have so far been used in the installation of oil plants, and are the starting point for the installation of wind turbines at sea.

- Compliant: Are of this type when the lowest natural frequency is below the wave power. Environmental forces cause deviation in these structures, but the magnitude of the dynamic loading is greatly reduced, which allows this type of structure to be cheaper to deeper waters from the type above.

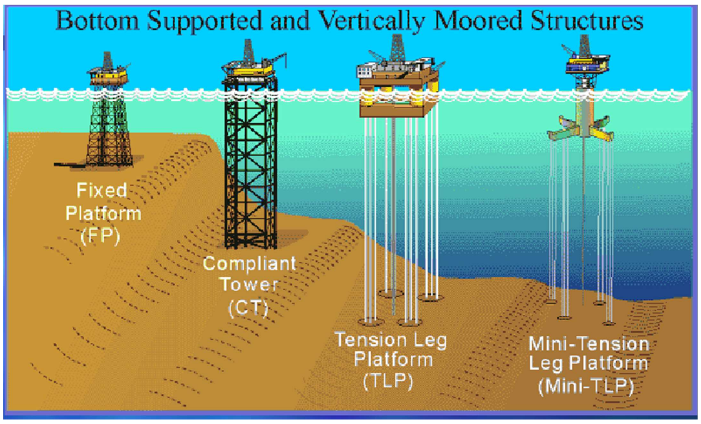

Figure 6: Types of structure

Below are the most common types of foundation with which is being currently working on offshore wind turbines, which are the foundation by gravity(GBS), the monopiles and tubular foundations of metal like tripod and jacket.

Gravity Based Structures (GBS):

The foundations of gravity were used to install the first experimental wind farms. They are surface foundations which are able to maintain stability at any condition, only by the weight of the structure.

Are competitive when environmental actions are modest or when the self-weight load is important, as an alternative if you are unable to install other structure or the cost of mobilization is high.

They usually have a cone shape because the first places where they were used was in the Nordic countries and these structures act as icebreakers to drift, with a diameter of 12 to 15 meters and from 500 to 1000 tons of weight.

The foundation is built in dry dock near the site where it will be installed, using reinforced concrete, and brought to the desired location where it is filled with sand and gravel to get the weight needed to submerge.

The disadvantage of this type of foundation is its cost, which is to be proportional to the square of the depth where you want to install, so this type of foundation is too expensive for depths greater than 10 meters. In addition, the seabed must be prepared by removing the first layer of subsoil.

Figure 7: Gravity based structure

A variant of this type of foundation is Gravity + Steel, instead of reinforced concrete, uses a cylindrical steel tube located in a steel flat on the seabed.

This type of foundation is considerably lighter than its predecessor, but ultimately when sink and fix it to the seabed must have a weight of approximately

1000 tons.

The base of a foundation like this will be 14x14 meters for a depth of 4 to 10 meters, depending on the wind turbine to ride.

Finally, to prevent corrosion is necessary to protect the steel structure with Paint.

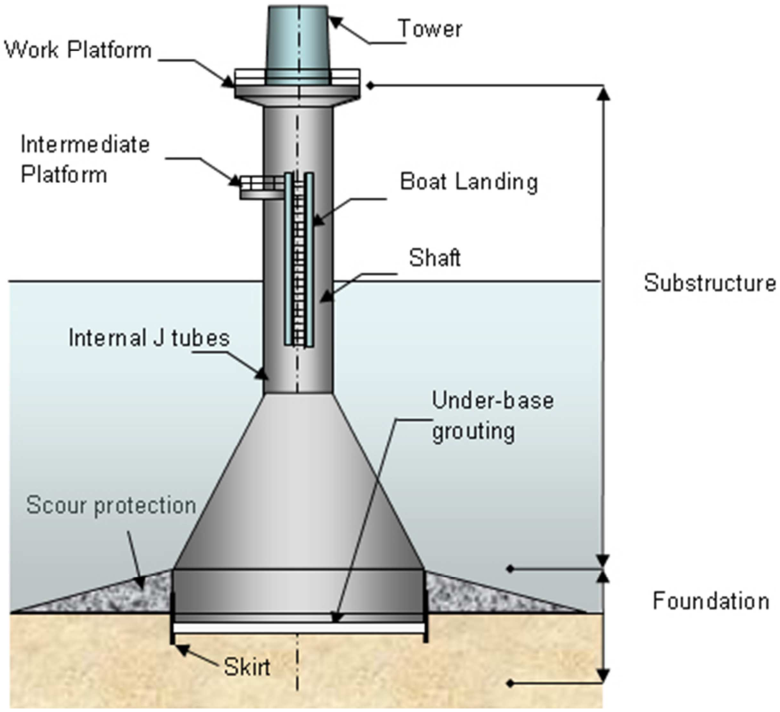

Figure 8: Structure of GBS

Monopiles

They are deep and individuals foundations that enter the field and manage the transmission of loads to it. They are used to install wind turbines of small and medium size, but could potentially be extended for use with large turbines. Its mass production and installation are simple, being the biggest problem to find suitable vessels for transport and assembly.

Monopiles structures installed in wind farms offshore are usually steel structures of more than 50 millimeters thick and a diameter of 3 to 8 meters. The concrete structures are also available.

The dimensions of the monopiles depend on many factors, such as penetration into the seafloor, which is usually dug between 10 and 20 meters. Has to be adjusted for each site location, analyze its characteristics and the loads that will support.

Structures are suitable for depths between 0 and 20 meters, discouraging their use for greater depths, due to its high flexibility, which can lead to problems of vibration and deflection.

Figure 9: Monopiles

The main advantage is that they are simple, lightweight and versatile, as they do not require fit out the seafloor.

However, as we have said before, the disadvantage is the difficult handling of them by their great length, which makes that require special cranes and driving. They also need to pre-dig the hole where they will be installed.

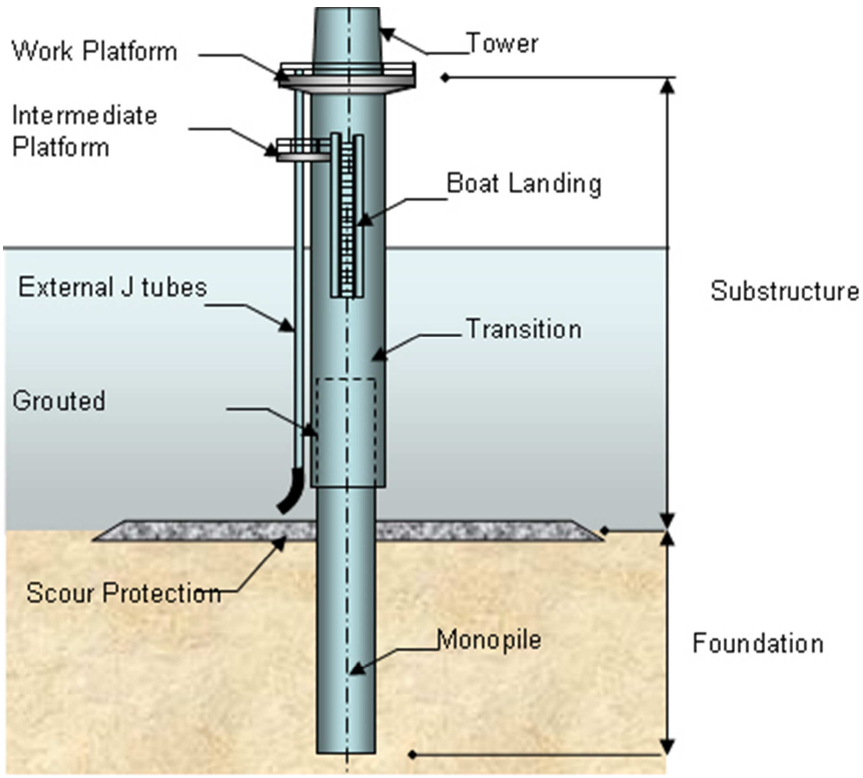

Figure 10: Structure of Monopiles

Tubular foundations of metal

Structures are inspired by oil rigs, where the most important for installation of wind turbines are the jacket and tripod.

They are a combination of the two previous systems foundation with intend to reach greater depths. Under field conditions can be placed as monopiles, or be supported by a concrete base such as the foundation by gravity, differentiated between them by the number of legs, three the tripod and four the jacket structure.

<u>Jacket structure</u>:

It is a structure composed of tube diameter of 1 and 2 meters soldiers, whose main performance characteristic is that the main columns are made of hollow tubes, which are housed inside the piles forming a shirt.

Once the structure touches the seafloor is anchored by these piles, which can reach a deep up to 100 meters deep. Their weigh is about 20,000 tons. This type of structure can support large vertical loads, and the wave force on it.

In order to avoid the effects of corrosion must protect steel pipes with paint. These structures are expensive in terms of production and installation.

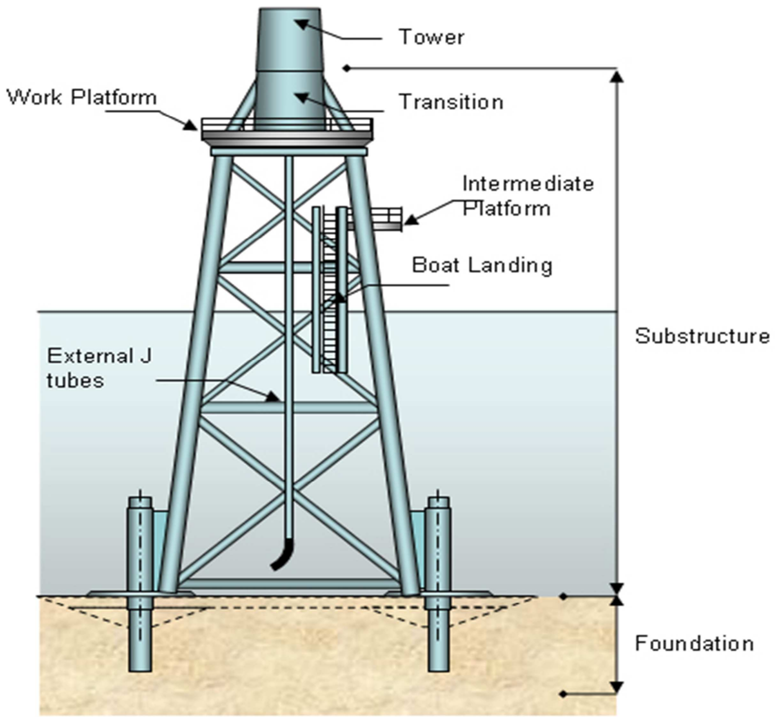

Figure 11: Jacket structure

Tripod structure:

The tripods structures are formed by tubes from 1 to 2 meters of diameter, which transmit the forces from the tower to the three piles that are stuck to the seafloor to a depth of 10 to 20 meters.

Being suitable for depths around 60 meters, the limitation imposed by the profitability is 18 meters maximum and more than 7 meters because of the risk of collision of vessels approaching service to the tower.

Tripods require a solid seafloor where fixing the micropiles, but the seafloor conditioning required is minimal. This is a very rigid structure and versatile, but has a construction and installation costs very high.

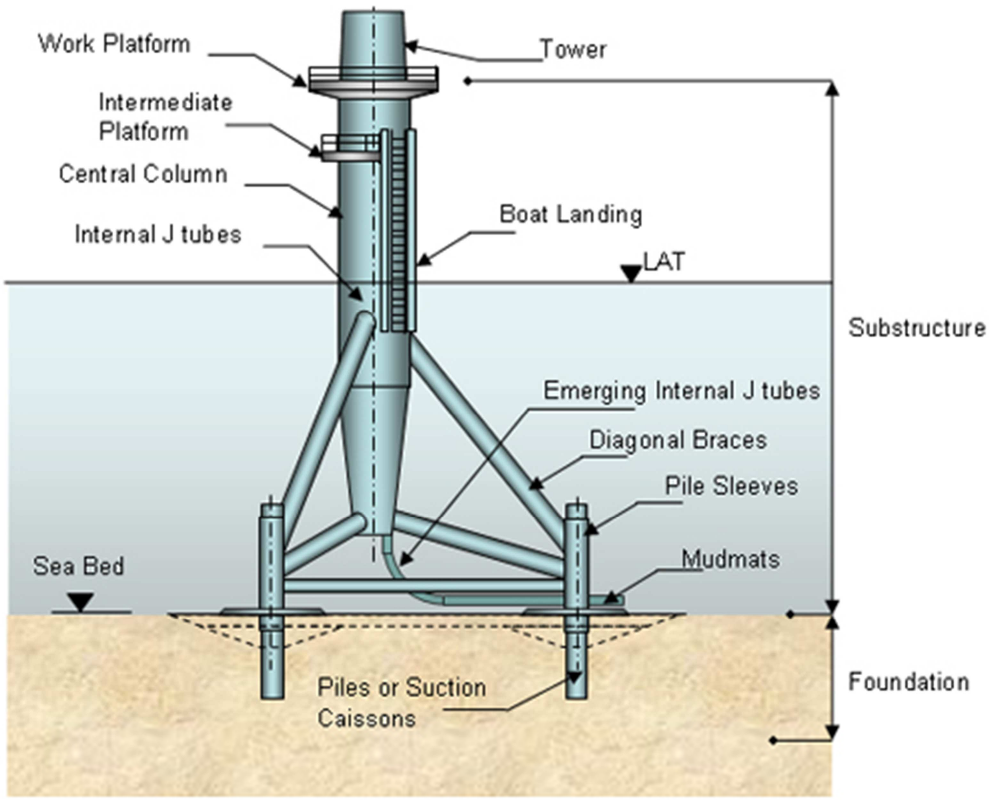

Figure 12: Tripod structure

3.3.2 FLOATING

Finally, we have another group of foundations, which are in a stage of study and research. These are floating structures. In high water depths and seabed rocky or difficult to install an offshore fixed, this type of substructures and anchors seem the most optimal and most promising. In this group we can distinguish three subgroups according to the type of system used to achieve stability in flotation:

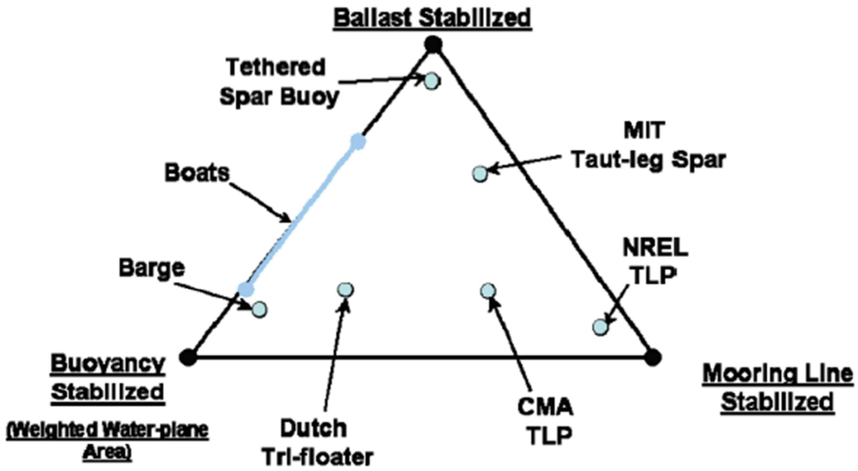

Figure 13: Triangle of stability of floating systems.

This figure is known as the triangle of stability of floating structures which shows the different approaches to achieve static stability in the floating structure. These concepts, which are located at the vertices of the triangle, are by weight stability, the stability of forms and stability by anchoring system.

Furthermore the stability triangle is intended to represent the fact that the concepts of floating structures are a combination of the three approaches.

The floating structures could then be ranked as follows:

- SPAR: stability achieved by weights, i.e. for ballast.
- Semisubmersible or Barge: obtained by stability of forms (Buoyancy).
- Tension Leg Platform (TLP): you get stability by anchoring system (Mooring Line).

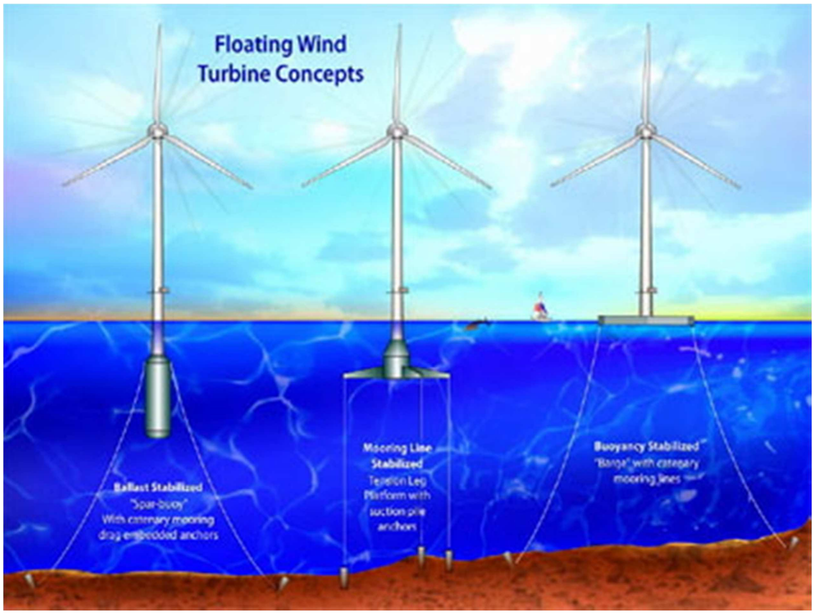

Figure 14: Floating structures

In the figure we can appreciate the three types of stable systems floating substructure. However it is important to note that the stability cannot be achieved by one of the concepts of pure form, but as a combination of them.

It is noteworthy that the use of media floating wind turbines involves modifications to improve the performance of the support assembly-turbine.

Today, in the field of floating platforms include four companies:

StatOil Hydro

Today the Norwegian company, mostly public, is possibly the most advanced in this type of technology. As part of a project to develop a wind farm on a commercial scale floating 10 km from the Norwegian west coast (Karmøy).

Initially, Statoil Hydro will operate Siemens turbines of 2.3 MW rated power with proven experience in marine environments, such as the Danish park Nysted on conventional platforms used for oil and gas extraction. In particular the named "Spar-buoy," consisting of a "float" metal cylinder filled with ballast water and rocks, which is secured to the seabed by three cables.

The target date for entry into operation of this park was located at the end of 2009.

The Norwegian company argues that technologies are the future for floating wind, and that despite the need for an initial effort, it could reach prices competitive with existing fossil fuels.

If the project comes to a successful conclusion, this type of marine parks would become one of the main design elements of Super-European network (European Supergrid), which is planned as a tool to enable networks to integrate a large proportion of renewable energy.

Figure 15: Statoil project

Sway

This Norwegian company is building jointly with Statoil Hydro, another floating wind turbine prototype. This prototype consists basically of a kind of buoy that can float up or down slightly with the waves, so this type of platform required less anchors than previous technology based on "Tension-Leg Platform".

In this case are used turbine blades 3 but with the leeward rotor rather than on the windward side as in conventional turbines.

The end of this project was planned during 2010.

Figure 16: Sway wind farm

Blue H Technologies

Blue H Technologies is a Dutch company that built its first experimental platform last year on the coast of southern Italy with an 80 kW wind turbine. Also, plan to install another turbine for testing near Massachusetts.

The platform proposed by Blue H Technologies is a platform "Tension-Leg" where the two-bladed wind turbines are installed. The choice of two bladed turbines is justified by the possibility of increasing the rotational speed of the turbines, without the noise is significant growth in the planned locations. In this way, it possible to reduce the torque and therefore get a lighter structure and a blade less. Specifically, the structure of the 2.5 MW turbine will weigh Blue H 97 tons, 53 tons less than the lightest machine on the market with 3 blades and the same benefits.

The company is developing a commercial offshore wind farm of 92 MW, which will be located at a site near the test location.

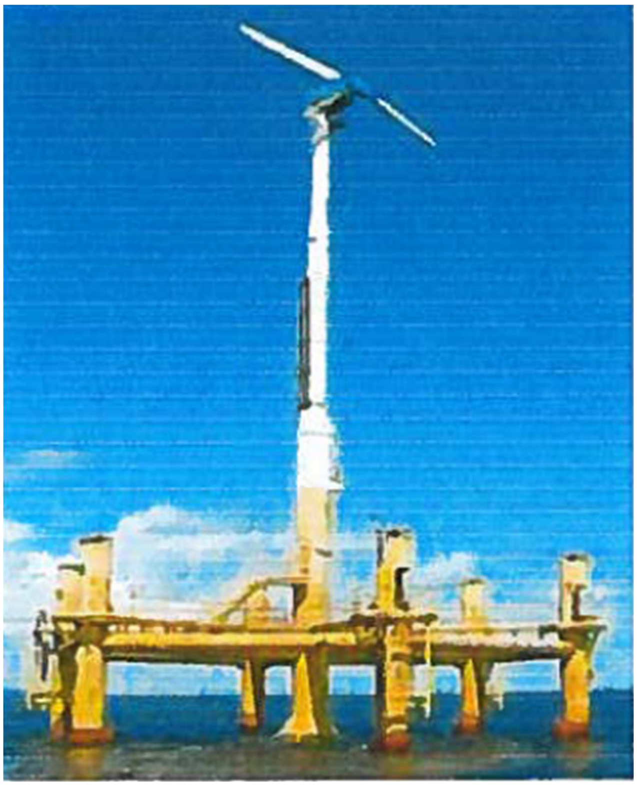

Figure 17: Floating Platform of Blue H

WindFloat

The company Marine Technology in the U.S. and has designed a new system of floating turbines with high rates of effectiveness for depths greater than 50 meters with a capacity of 5MW.

It is a magnificent structure with a stable, highly versatile and shallow draft. With a design that allows the structure to be mounted entirely on land and towed to its final location, keeping all manufacturing in a controlled environment, with its consequent cost saving implementation.

Figure 18: WindFloat platform

New Ideas

Is currently being investigated in more complex geometries where several turbines are placed on the same substructure, but the concept of anchoring and mooring system to the sea is still under previous approaches of stability.

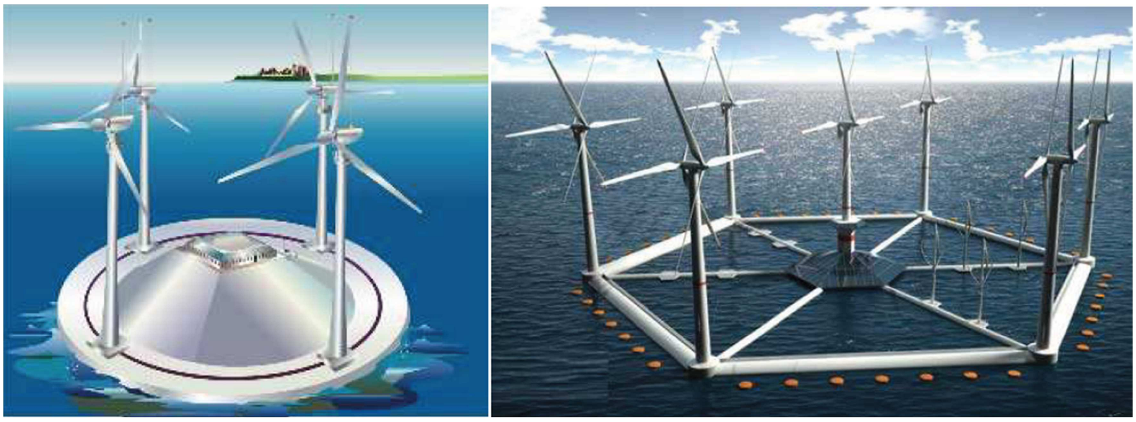

Figure 19: Ideas of platform that share wind turbines

CHAPTER 4: POWER SYSTEM

4.1 UNDERSEA CABLE

Alternating current (AC)

It is the cheapest solution for small parks and distance to the coast less than 20 km. It uses turbines of 33kV and connected by alternating current cable of the same power. A single cable can support up to 300 MW. The energy is conducted directly to ground without the offshore substation.

We should note that faces severe voltage drops caused by high transmission losses.

Figure 20: Power system

High voltage alternating current (HVAC)

For projects larger than 100 MW, the electrical power generated can be transmitted by cables as higher capacity 132 kV or higher.

The offshore substation is necessary. This solution is optimal for medium-size projects and 20 km of distance to coast.

A 132kV cable can handle up to 250 MW. As parks increase in size or increasing distance offshore, HVAC cables have limitations caused by excessive losses. After a certain length of cable, transmission losses (along with other aspects of costs) make not feasible AC cables.

Figure 21: Substation

High voltage direct current (HVDC)

The alternative to the HVAC cables is to use HVDC cable. There is no experience in offshore. The transmission losses are around 20% lower than AC cables, although, due to cost and losses in the converters are only profitable from 100 km offshore.

Figure 22: Undersea cables

CHAPTER 5: LOAD STUDY

5.1 INTRODUCTION

Currently the design of marine structures for the installation of wind turbines at sea is in a stage of research and development. The most important line of work is in software development and correlation of existing software packages for a reliable and realistic calculation of the structure.

Wind turbines located offshore are designed and analyzed using complex simulation codes which should take into account the dynamics of wind flow, aerodynamics, elasticity, and controls the wind, the waves incident on the substructure, hydrodynamics and dynamics of the foundation which supports the structure on the seafloor. There are programs with great historical development and experience for the turbine aeroelastic calculation, but there is a problem of integration of the various physical problems in a single package.

The Offshore Code Comparison Collaborative (OC3) is an organization created in Europe to bring together the producers of marine structures codes so you can compare the latest developments and share experiences on the implementation thereof.

Another significant challenge is in the measurement of the characteristics of marine environments, winds, waves and currents. Despite the existence of maps of winds and seas, to the design of the turbine installation, it is important to measure the exact point where it will be installed. To make these measurements is needed to develop new technologies of measuring devices, such as might be the anemometer cups, blades for wind direction, the sonic anemometers, and remote sensing such as LIDAR (Light Detection And Rank) and the SODAR (Sound Detection And Rank) and the installation of measurement platforms.

On the other hand, companies in charge of the design of wind turbines are beginning with the development of new turbines, not only more powerful but also turbines that are best suited to the conditions and requirements of the location at sea.

Finally, it is also important to develop new technologies for ship installation, operation and maintenance of the substructures at sea.

5.2 STRUCTURAL DESIGN

The process of designing a wind turbine located at sea should follow an iterative process as reflected in the following diagram.

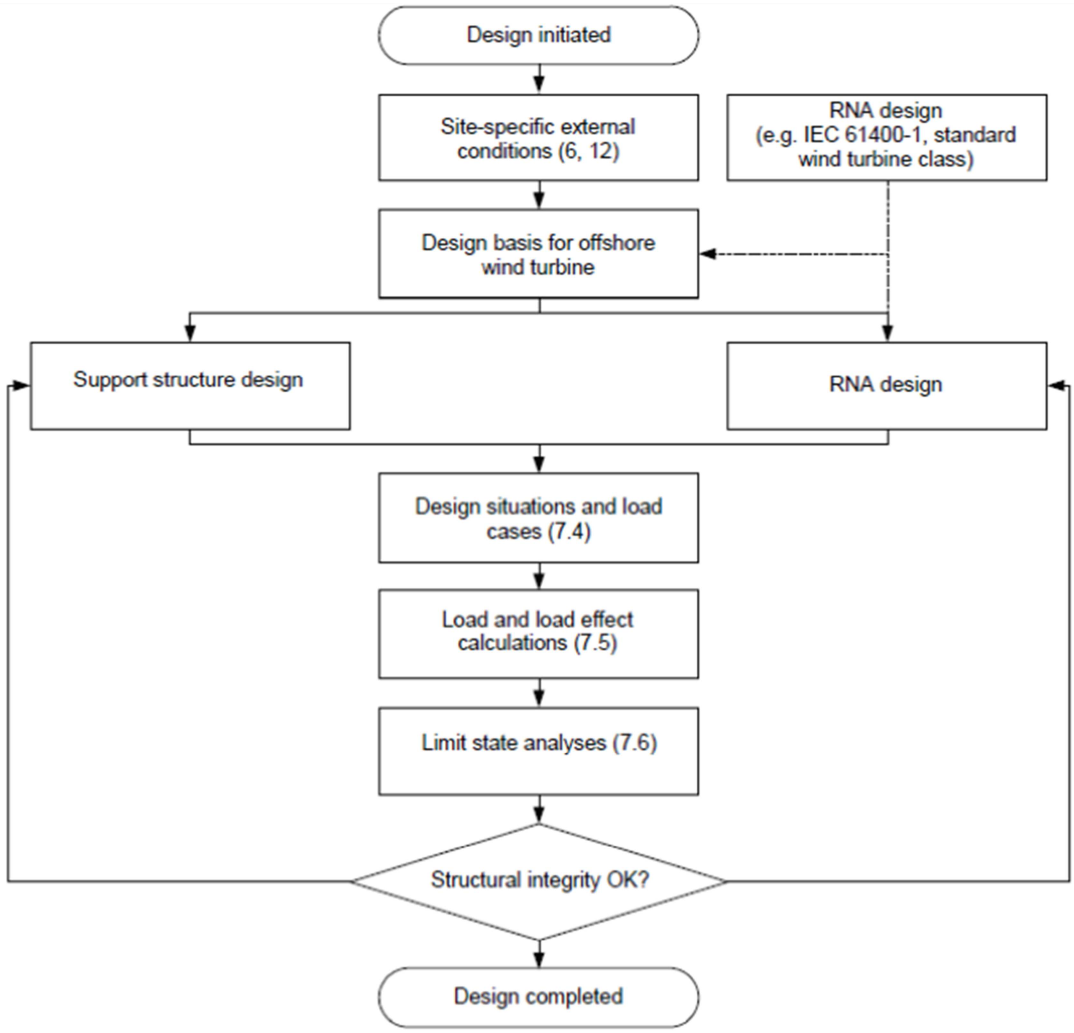

Figure 23: Design process

The integrity of structural components that have to support a load of offshore wind turbine must be verified and be within safe levels determined. The resistance of members to fatigue and ultimate load must be verified by calculation and, or laboratory testing of scale models to demonstrate the structural integrity to a level of security appropriate.

The calculation must be made with appropriate methods. In the design documentation shall be collected a description of the calculation methods used in the analysis. The description should include evidence of validation of methods of calculation or references to studies that verified.

The main design criteria for the realization of this Final Project are:

- The design life of the turbine must be at least 20 years.
- The designer must specify the model and the characteristics of the turbine that have been used to design.
- Characterization of wind and sea conditions (waves, sea current, seabed properties and their evolution over time, other properties such as marine growth or impact of ice blocks, etc..) Must be carried out as described in the following section of this document, "Characterization of stresses on offshore platform."

Load cases to be analyzed under the design criteria to verify the integrity of the structure are the combination of:

- Normal design situations and normal or extreme external conditions.
- Lack design situations and appropriate external conditions.
- Design situations during transport, installation and maintenance with appropriate external conditions.

You can only give completed the design of the turbine when its structural integrity has been verified.

The design and structural analysis of the foundation or substructure where rests the offshore wind turbine must be performed according to ISO standards for the design of marine structures.

The substructure must be designed to support both static and dynamic loads.

Applying loads to fatigue and cause damage during transport and installation of substructures should be taken into account. In the event that the substructure will be subject to the seabed by means of piles, should be verified also with a specific analysis of the soil-pile-structure, taking into account the dynamics of this binding.

The following diagram shows the process design of the offshore substructure:

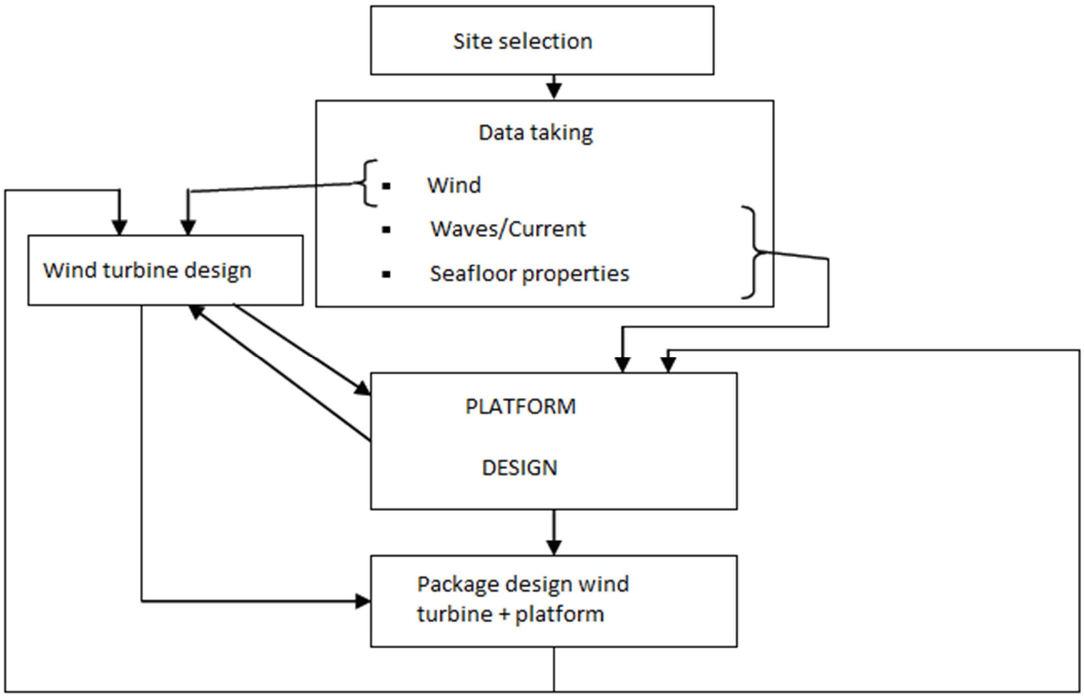

Figure 24: Preliminary process of design of the platform

5.3 CHARACTERIZATION OF STRESSES ON THE OFFSHORE PLATFORM

The main requests on a wind turbine located at sea which must be taken into account in structural analysis are reflected in the following figure:

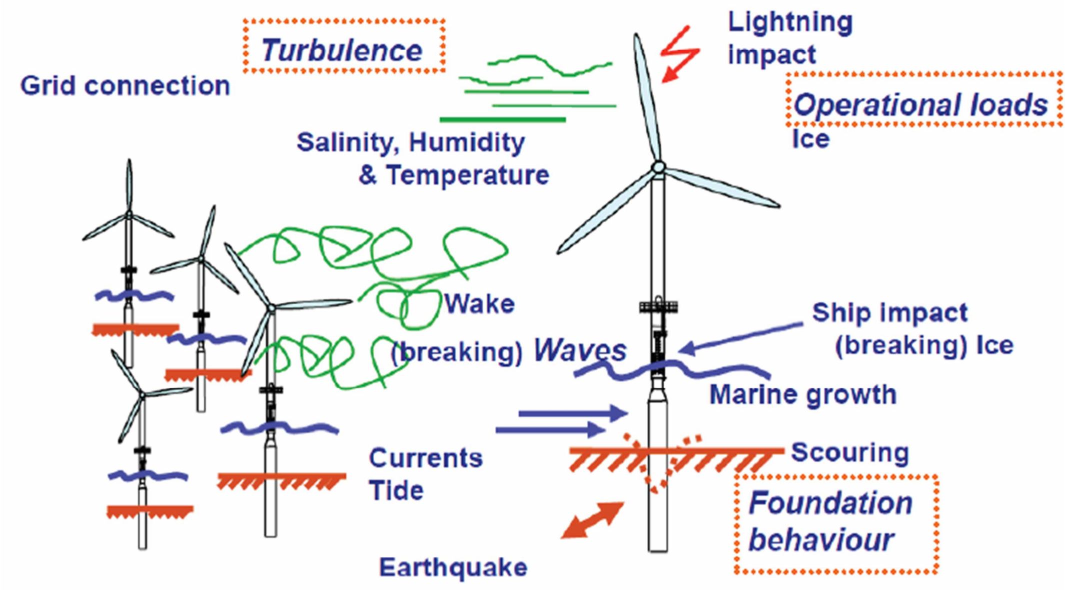

Figure 25: Environmental loads on offshore wind turbine

All these cases of loads are collected in the standard. However, we cannot check all of them. There is no option but to calculate the loads due to waves, steady wind and the behavior of the seabed.

The following explains how to calculate all these actions.

5.4 ACTIONS DUE WAVES

The wave action is the mechanical impulse generated by the impact of particles of water against the structure. To understand why this impact occurs first is necessary to know the characterization of the kinematics of the water particles in a sea state and the elevation of the sea surface.

There are different approaches to perform this characterization. Depending on the control of structural response tests can be classified into:

- Temporal analysis.
- Frequency analysis.

In addition they can be made with variable random or deterministic. It has two different calculation approaches to quantifying the same phenomenon, although it is convenient to emphasize that the statistical implicit in each one of them is the same. It depends on the designer and the recommendations that the rules make.

5.4.1 TIME CONTROL. CLASSICAL HYDRODYNAMICS

The waves are mechanical shallow waves. So, they are the propagation of a disturbance in a material medium (water) through the interface between two media (sea water and air in this case).

The origin of ocean waves and the forces involved in the generation and propagation is very diverse. This makes the range of periods of oscillation of the same is varied, a few tenths of a second (capillary waves) to several years (waves caused by global climate change).

It is important to know some properties. Generating agent is one which causes the water to rise forming the wave, and the restoring force causing the water to return to the original smooth surface, so that the disturbance causes the progress, the wave shift.

The most important waves taken into account in the design of a substructure are those generated by the wind and the restoring force because they have the highest energy content. Besides the frequencies are close to the natural oscillation of the substructures marine and the wavelengths are the same order of magnitude as the main dimensions of such systems. These waves are produced by the energy exchange between wind and water, demonstrating the need for information correlated to wind and waves, as they are not completely independent events.

To describe the phenomenon of waves there are several theories of ideal waves. These theories model the waves like recurring events, and are all regular. The most common is the Airy theory which is linear.

Here's linear wave theory or theory of Airy.

To apply this theory is required to observe some hypothesis:

- Water is homogeneous and incompressible (so the density is constant).
- The surface tension can be neglected.
- The Coriolis effect due to rotation of the Earth also can be neglected.
- The pressure on the free surface of the sea is uniform and constant.
- Seawater is lacking in viscosity.
- There is no wave interaction with any other marine movement. The flow is irrotational.
- The sea floor is a horizontal boundary, fixed and impermeable, which means that the vertical speed is zero.
- The wave amplitude is small and its shape is invariant in time and space.
- The waves are flat (two dimensional).

In general, the waveform is characterized by its length, L, height, H, its period, T, and the depth, d, on which is spread. The water depth will have a great influence on the shape of the wave and the propagation velocity is determined by all of them. Another important property is the direction of propagation of the wave front and the size of the crest of the wave.

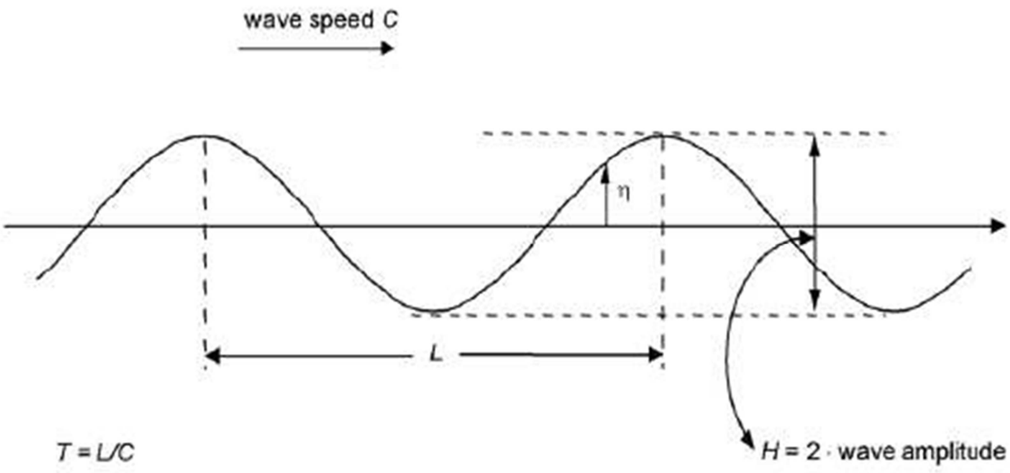

Figure 26: Representation of an Airy wave

While raising the sea surface shows a spread of the wave, the water particles beneath the surface are making an orbital motion. Within the framework of the Airy wave theory, the orbits are closed curves: circles in the case of very deep water and ellipses in shallow water. The radius of these curves decreases exponentially with the depth at which the particle is water under study. This effect can be seen in the following figure:

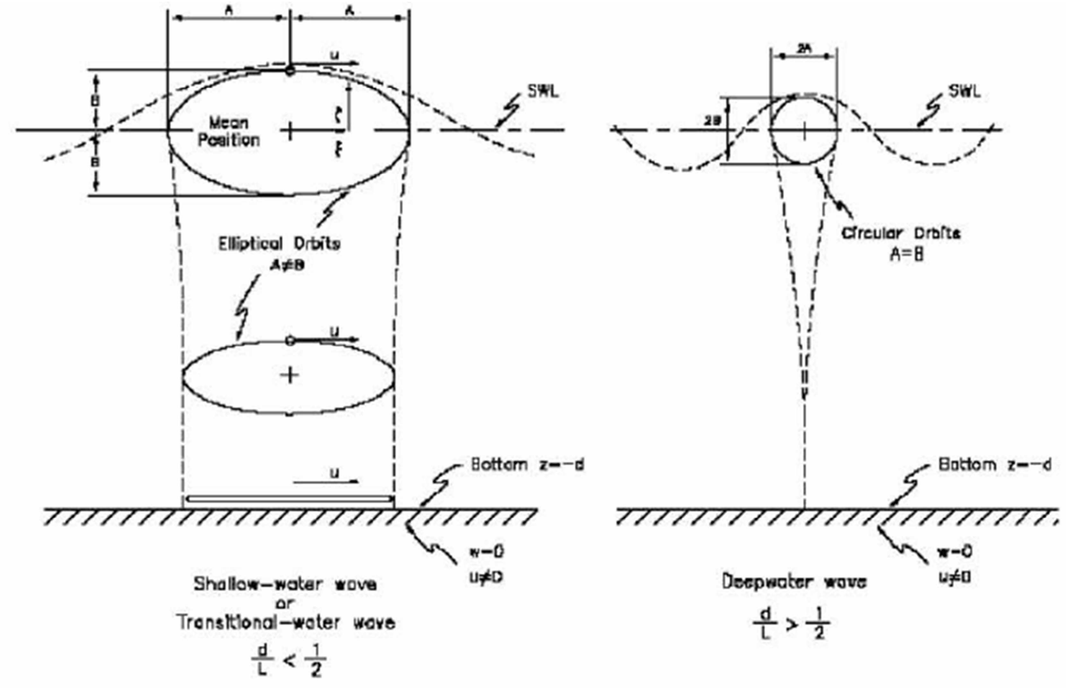

Figure 27: Orbital motion of water particles beneath the sea surface

From these data we can define a velocity potential ϕ dependent on the position (x, z) of the particle in the fluid and the time t into account, the formulation is as follows:

$$\phi = \frac{a\omega}{k}\frac{\cosh[k(z+d)]}{\sinh kd}\sin(kx - \omega t)$$

Where

- a = wave amplitude (H / 2)
- ω = wave frequency (rad / s)
- k = wave number
- d = depth of the sea

From this potential we can calculate the speed of the particle and the dispersion of water waves. The following table lists the general equations and theoretical solutions provided by the Airy theory of the kinematics of the particle of water:

Relative Depth	Shallow Water $\frac{d}{L} < \frac{1}{25}$	Transitional Water $\frac{1}{25} < \frac{d}{L} < \frac{1}{2}$	Deep Water $\frac{d}{L} < \frac{1}{2}$
1. Wave profile	Same As >	$\eta = \frac{H}{2}\cos\left[\frac{2\pi x}{L} - \frac{2\pi t}{T}\right] = \frac{H}{2}\cos\theta$	< Same As
2. Wave celerity	$C = \frac{L}{T} = \sqrt{gd}$	$C = \frac{L}{T} = \frac{gT}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$	$C = C_0 = \frac{L}{T} = \frac{gT}{2\pi}$
3. Wavelength	$L = T\sqrt{gd} = CT$	$L = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$	$L = L_0 = \frac{gT^2}{2\pi} = C_0 T$
4. Group velocity	$C_g = C = \sqrt{gd}$	$C_g = nC = \frac{1}{2}\left[1 + \frac{4\pi d/L}{\sinh(4\pi d/L)}\right]C$	$C_g = \frac{1}{2}C = \frac{gT}{4\pi}$
5. Water particle velocity (a) Horizontal	$u = \frac{H}{2}\sqrt{\frac{g}{d}}\cos\theta$	$u = \frac{H}{2}\frac{gT}{L}\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\cos\theta$	$u = \frac{\pi H}{T}e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
(b) Vertical	$w = \frac{H\pi}{T}\left(1+\frac{z}{d}\right)\sin\theta$	$w = \frac{H}{2}\frac{gT}{L}\frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\sin\theta$	$w = \frac{\pi H}{T}e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
6. Water particle accelerations (a) Horizontal	$a_x = \frac{H\pi}{T}\sqrt{\frac{g}{d}}\sin\theta$	$a_x = \frac{g\pi H}{L}\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\sin\theta$	$a_x = 2H\left(\frac{\pi}{T}\right)^2 e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
(b) Vertical	$a_z = -2H\left(\frac{\pi}{T}\right)^2\left(1+\frac{z}{d}\right)\cos\theta$	$a_z = -\frac{g\pi H}{L}\frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\cos\theta$	$a_z = -2H\left(\frac{\pi}{T}\right)^2 e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
7. Water particle displacements (a) Horizontal	$\xi = -\frac{HT}{4\pi}\sqrt{\frac{g}{d}}\sin\theta$	$\xi = -\frac{H}{2}\frac{\cosh[2\pi(z+d)/L]}{\sinh(2\pi d/L)}\sin\theta$	$\xi = -\frac{H}{2}e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
(b) Vertical	$\zeta = \frac{H}{2}\left(1+\frac{z}{d}\right)\cos\theta$	$\zeta = \frac{H}{2}\frac{\sinh[2\pi(z+d)/L]}{\sinh(2\pi d/L)}\cos\theta$	$\zeta = \frac{H}{2}e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
8. Subsurface pressure	$p = \rho g(\eta - z)$	$p = \rho g\eta\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)} - \rho g z$	$p = \rho g\eta e^{\left(\frac{2\pi z}{L}\right)} - \rho g z$

Figure 28: General equations posed by Airy theory

In case you want to describe an irregular sea, i.e. represent a more real sea state, it is necessary to use a probabilistic approach which describes the short term and locally irregular sea. The elevation of the sea surface is considered a random process that depends on the space and time, but is simplified so that does not depend on either as refers to the state of the sea to a short term and locally. In fact, statistics say that the surface elevation of irregular sea is a homogeneous, stationary and ergodic as long as they study in the short term, 3 hours, and in a circle of about 60 miles in diameter, i.e. , locally.

According to the characteristics of the sea, the energy spectrum follows one form or another. There are two main types of spectra by which they can define almost all European seas. These are the spectra of type JONSWAP and Pierson-Moskowitz. The first is the acronym for Joint North Sea Wave Project and is characteristic of the North Sea as its name suggests and defines seas aggressive, brave, to achieve higher energy content. The spectrum of Pierson-Moskowitz type is however characteristic of calmer seas and constant, as in the Mediterranean Sea for example. The following figure shows the comparison between the shapes of both spectra on the same graph:

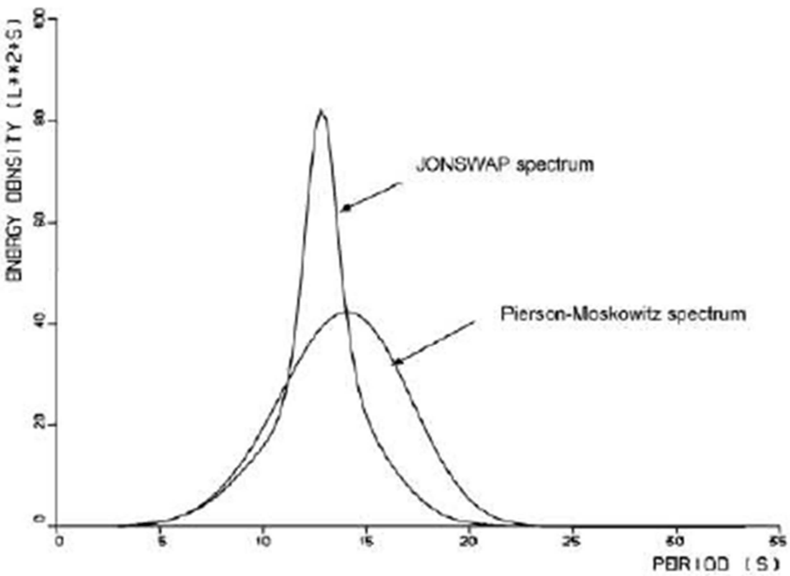

Figure 29: Energy density spectra

Having defined the shape of the energy spectrum should quantify the dimensions of the curve, using the values that determine the peak of the curve of the spectrum:

- Significant wave height: is defined as the average value of one third of the largest recorded heights, Hs.
- Period zero crossing or peak: corresponds to the frequency associated with the maximum energy of the sea, i.e. the maximum of the spectral function, Tz.

5.4.2 MORISON THEORY

Everything that has been explained until now refers to how to characterize the elevation of the sea. The following will explain how these waves and sea states request the structure, i.e., calculating the loads on the structure. The theory explaining this phenomenon is the theory of Morison.

The Morison equation is used to calculate the hydrodynamic forces on slender bodies, such as members of the truss beam sea. This means that the diameter of the cross section of the member, D, must be less than 1/5 of the wavelength of the incident wave, L.

For higher diffraction parameters apply other theories

The calculated hydrodynamic force Morison equation is divided into a component of calculation of viscous drag and another one which calculates the inertia loads on the bar structure.

$$F = \frac{1}{2} C_d \rho D |U| U + C_m A \dot{U}$$

Where:

- F is the force per unit length on the member.
- Cd is the drag coefficient.
- Cm is the ratio of inertia.
- ρ is the density of water.
- D is the diameter of the member.
- A is the cross sectional area of the member.
- U is the velocity of flow normal to the member.
- $\dot{U}$ is the normal flow acceleration member.

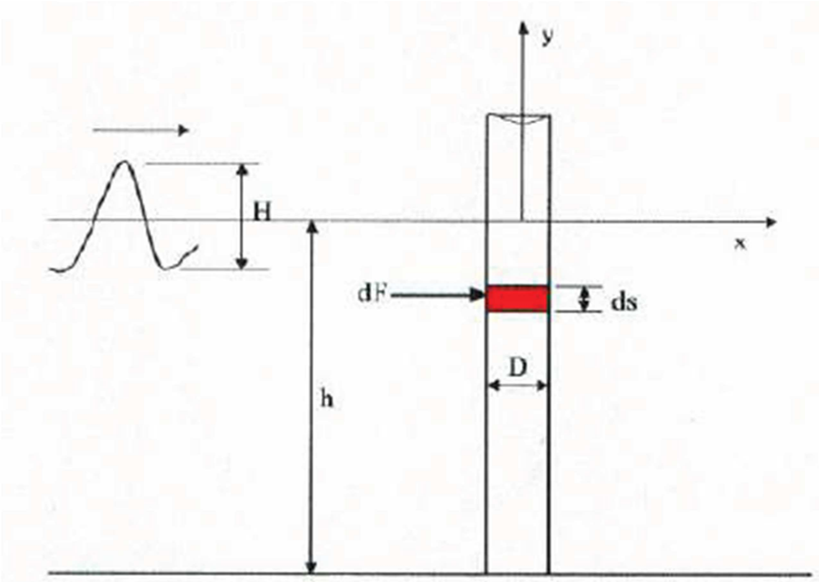

Figure 30: Definition of the wave load on the cylinder.

If the structure has significant displacement, relative velocity changes the drag force and may be a hydrodynamic damping. The relative acceleration results in a force similar to the inertial force which can be more conveniently analyzed using the concept of added mass of water, which is constrained to move with the structure. If so, you must perform a dynamic model of the structure as is indicated in the regulation. In this case, the Morison equation becomes:

$$F = \frac{1}{2} C_d \rho D |U_r| U_r + C_m \rho A \dot{U}_w - C_a \rho A \dot{U}_s$$

Where

- Ur is the normal flow velocity relative to about member
- $\dot{U}_w$ is the normal acceleration of the flow to the member.
- $\dot{U}_s$ is the normal acceleration structure member.
- Ca is the added mass coefficient (Ca = Cm-1 for cylindrical members, slender fixed structures).

The values of the coefficients Cd and Cm are in the standards for the designer to take their appropriate values.

5.5 ACTIONS DUE WIND

We define two types of wind turbine affecting: deterministic and stochastic wind.

The deterministic wind is the one without turbulence. The standard defines various gusts and each is governed by an equation in which the wind speed varies differently over time. Furthermore the speed of wind is also modified by other factors such as wind profile that makes take a different rate depending on the height or the shadow effect of nearby machines. With these equations yields a wind speed which varies according to these equations but it is constant, and they get extreme load cases due to wind. With these maximum values of wind speeds that are more damaging to the overall structure of the turbine are carried out analyzes of ultimate load.

The other hand is the wind stochastic where there is turbulence in the three directions of space. This type of wind is much more complex to simulate. It generates a grid of points covering the whole rotor and the turbine facing the entire area, including the tower, which are the points where it is estimated wind speed. Furthermore, it is considered a "fourth dimension" which is the variation in time of that speed. You should then choose a turbulence model. These models are models which energy and generate a spectrum of wind is based on measurements taken. A wind is created from the spectrum of wind that is also consistent at the points of the mesh to ensure that there is continuity in wind speeds. The standard shows the number of turbulence to create and the minimum time of wind to consider a state of wind fatigue analysis, which is 10 minutes. The wind very turbulent is used for the fatigue analysis.

After calculating the wind speed, the force on the turbine structure and is limited to Equation Morison again, only this time not taken into account the added mass term because is negligible as compared with the drag term be the mid-air:

$$\vec{F} = \frac{1}{2} C_d \rho D \left|\vec{U}\right| \vec{U}$$

Where:

- F is the force exerted by the wind.
- Cd drag coefficient of wind drag.
- ρ air density.
- D diameter of the area facing.
- $\vec{U}$ wind speed.

5.6 OTHER ACTIONS

The regulation indicates that the structural integrity check against multiple actions such as ocean current, ocean growth, ice impact, impact of a ship, the effect of water corrosion on the structure, machine failures, etc.

These will not be considered in the analysis performed for this Degree Project because this is a preliminary study of the entire design process.

CHAPTER 6: COSTS

An offshore project requires high initial investment, because of the structures needed to support the turbine and the connection to the network. Thus the large megawatt projects are more profitable.

The cost structure of offshore wind farm is:

- Foundation Cost: The cost for gravity foundations is quite high, partly because of the large amount of material required for construction and partly by the cost of transport to the final location. This was the reason why now the balance has declined to the monopile constructions, since weight reduction is considerable, but after looking at projects, floating structures are being developed because reduce even more costs.
- Cost of power connection: The electrical connections within the wind farm are usually carried around 11KW, while the outbound connection is made depending on the total power of the wind farm. On the other hand, in connection with the distribution network is very likely that the cables are buried in the seabed, but the connection cables between turbines can be outside and can cause accidents in fishing activities. For this reason it is essential to bury these cables and must assume also the additional costs.
- Turbine Cost: The cost would include more wind turbine auxiliary equipment for operation.
- Costs of planning: In planning would include the measurement of the wind resource, the environmental impact study and analysis of profitability of the park.
- Various costs: the cost would consist of financial, insurance and operating and maintenance activities during construction of the park.

Comparing the costs of an onshore facility with offshore values is:

	Onshore (%)	Offshore (%)
Foundations	5.5	16
Wind turbine	71	51
Electrical connection between turbines	6.5	7
Electrical connection with the distribution network	7.5	18
Engineering and administration	2.5	4
Various	7	4
Total	100	100

Figure 31: Cost in percentage

CHAPTER 7: FUTURE IN EUROPE

The European Commission anticipated, in its 2008 Communication on offshore wind energy (EC) that offshore wind can and must make a substantial contribution to meeting the EU’s energy policy objectives through a very significant increase - in the order of 30-40 times by 2020 and 100 times by 2030 - in installed capacity compared to today. It's all part of a plan to boost renewable energy from 8.5 percent of European energy consumption to 20 percent by 2020--and even more thereafter. This plan called for construction of regional electric transmission connections across the North Sea, around the Baltic region, and around the Mediterranean Sea, to distribute solar and wind power to and across Europe.

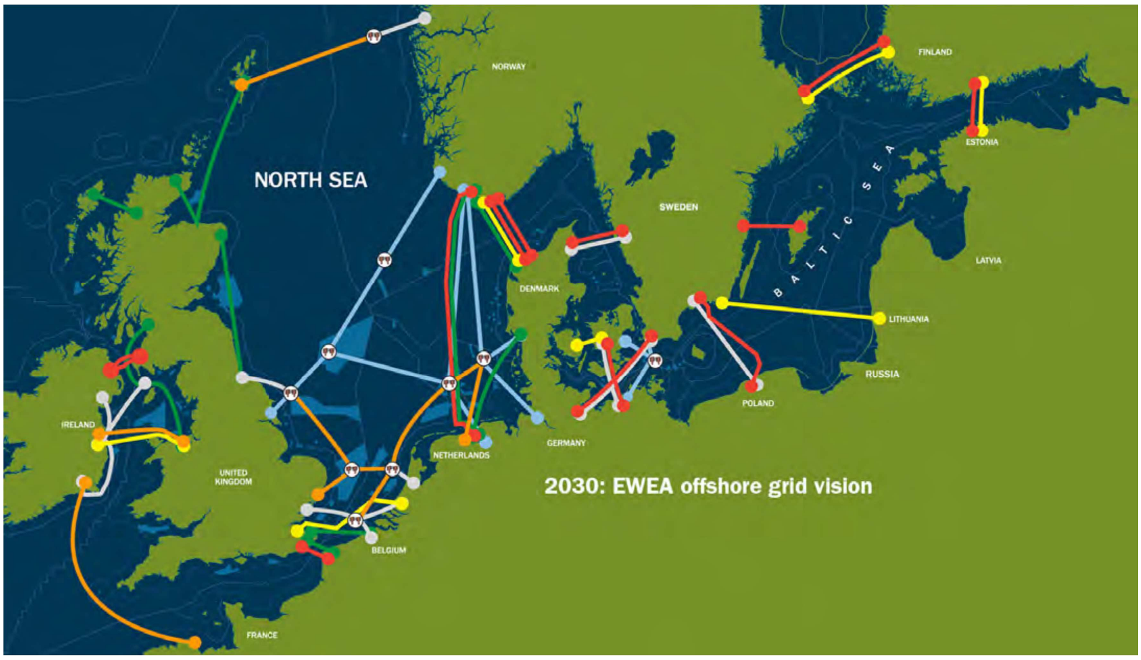

Figure 32: Supergrid

But the EC, the European Union's executive body, acknowledges that getting these so-called supergrids built will mean forging new agreements between European countries for transmission planning and investment--much as the United States needs more cooperation between states to, for example, move wind power from the Midwest to major cities. The wind power which consumers demand cannot be delivered without new networks, the EC report says, and there is little strategic planning between nations to build the required connections.

However, several recent developments suggest that progress on transmission between European nations is possible. In 2008, for example, a negotiator appointed by the EC convinced France to accept a new transmission connection with Spain, breaking a 15-year impasse over expanding power exchanges between the countries. Use of high-voltage DC (HVDC) technology will enable planners to bury the new line and thereby overcome local opposition to conventional overhead AC transmission lines.

Meanwhile, proposals for HVDC grids to deliver clean power from offshore wind farms to European consumers are getting more detailed. For example, Brussels-based environmental consulting firm 3E mapped out a blueprint for what a North Sea offshore wind-power grid might look like. In 3E's design, 3,500 miles of underwater HVDC cables crisscross the North Sea, forming a network capable of hooking up 68,000 megawatts' worth of new offshore wind farms--enough generating capacity to meet 13 percent of the region's power consumption.

Still, political challenges remain. EC points to a set of wind farms for Kriegers Flak, a shallow sandbar in the Baltic where the territorial waters of Denmark, Sweden, and Germany converge. Each country plans to build three of the world's largest offshore wind farms--up to 640 megawatts each, about the size of a medium-size coal plant--within a few miles of each other, yet without coordinated transmission. But it make no sense that what they say. They are talking about taking one grid into Sweden, and one into Germany, and one into Denmark.

Such efforts could pave the way to an entirely fossil-free power supply in Europe, much as Al Gore has proposed for the United States. Modeling by Gregor Czisch, an energy consultant in Kassel, Germany, shows that in theory, Europe and North Africa can source all of their electricity from renewable sources using a supergrid with conventional HVDC lines that can shift power thousands of miles with minimal losses. In this vision, wind power provides 70 percent of Europe and North Africa's energy needs, and Scandinavian hydropower serves as the backup battery, while African solar farms and distributed biomass-fueled power plants play supporting roles.

For the time being, 150 GW of offshore wind projects are in various stages of planning. A total of 1,247 offshore turbines are now installed and grid connected in European waters, bringing total installed capacity to 3,294MW, spread across 49 wind farms in nine European countries.

In the first six months of 2011, 101 new offshore wind turbines, totalling 348.1MW were fully grid connected (up 4.5% compared to the same period 2010). Overall 11 offshore wind farms were under construction during the period. Once completed, they will represent a total installed capacity of 2,844MW.

	Online	Under construction	Consented	Planned	Total projects	Size of government concession zones or foreseen future tender zones
Belgium	195	462	750	450	1,857	2,000
Denmark	854	0	418	1,200	2,471	4,600
Finland	26	0	765	3,502	4,294	n/a
Estonia	0	0	1,000	0	1,000	n/a
France	0	0	0	6,000	6,000	6,000
Germany	195	833	8,725	21,493	31,247	8,000
Greece	0	0	0	4,889	4,889	n/a
Ireland	25	0	1,600	2,155	3,780	n/a
Italy	0	0	162	2,538	2,700	n/a
Latvia	0	0	200	0	200	n/a
Malta	0	0	0	95	95	95
Netherlands	247	0	1,792	3,953	5,992	6,000
Norway	2	0	350	11,042	11,394	n/a
Poland	0	0	0	900	900	n/a
Portugal	0	0	0	478	478	n/a
Spain	0	0	0	6,804	6,804	n/a
Sweden	164	0	991	7,124	8,279	n/a
UK	1,586	4,308	588	42,114	48,596	47,000
Total Europe	**3,294**	**5,603**	**17,341**	**114,737**	**140,976**	**73,695**

Figure 33: Offshore capacity in Europe

EWEA anticipates an annual market in 2011 of approximately 1,000 MW. Depending on the amount of wind power installed onshore, it looks as if Europe’s 2011 offshore market could make up approximately 10% of Europe’s total annual wind market, making the offshore industry a significant mainstream energy player in its own right.

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